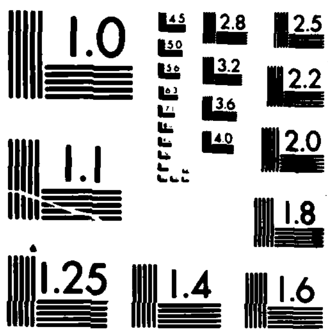
AD-A161 000 RADIATION EFFECTS PROGRAM(U) KM SCIENCES ARLINGTON VA 1/1
13 SEP 85 N00014-84-C-2230

UNCLASSIFIED F/G 20/7 NL

KM

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU-OF STANDARDS-1963-A

2

AD-A161 000

KM SCIENCES

SCIENCES

SCIENCES

SCIENCES

SCIENCES

SCIENCES

SCIENCES

FINAL REPORT IN SUPPORT OF THE RADIATION EFFECTS PROGRAM

Work performed during the period 1, July, 84 to 13, Sept., 85.
This work is in fulfillment of the terms of
contract n00014-84-C-2230

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	[illegible] and/or Special
A-1	

KM Sciences
1416 S. 28th St. Suite 3
Arlington, VA 22206

TABLE OF CONTENTS

A FEASIBILITY STUDY OF A LINAC BASE BEAM HEATING FACILITY

prepared by

KM Sciences

Introduction:

Interest has been expressed in the need for a facility capable of uniformly heating materials, such as composites. The heated volume must be sufficient for measurements to be made of basic material properties. This heating should take place at a rate of from 100 to 1000 calories per gram per second. Such heating can be produced by a beam of relativistic charged particles at or near minimum ionizing energies.

A beam consisting of 10 MeV electrons would penetrate 4.8 centimeters in water, hence they would pass through a carbon sample 2 centimeters thick depositing their energy quite uniformly. If the beam were a few centimeters in diameter one could uniformly heat a useful sized sample. The current required can be estimated from the following relationship:

$$dq/dt = P \times 4.2 \times 10^{5} \text{ calories per gram per second.}$$

The current density, P, is in amperes per square centimeter, and this equation assumes 10 MeV electrons on carbon. From the above relation one finds a current density of 2.4 milliamperes per square centimeter. To irradiate 10 square centimeters would require an average beam current of 24 milliamperes. Or, for 10 MeV electrons, an average beam power of 240 kilowatts. This is a prodigious amount of beam power but well within present day technical capability. The choice of 10 MeV provides sufficient penetration to be useful. To go to higher energy would increase the cost linearly with energy. there are other advantages to keeping the energy low. First, most thresholds for photonuclear reactions are at or above this energy, hence little or no radioactivity would be produced and therefore few neutrons. Also, since x-ray production is proportional to the square of the electron energy, one wants to keep the energy low to minimize shielding problems. The energy loss of relativistic electrons as they pass through material is quite uniform until their energy gets down to a few mev. Then the scattering starts to spread the beam significantly and the energy deposition per cm. of path starts to rise. While a 10 MeV electron beam would have 1 to 2 cm of uniform energy deposition in carbon, a 5 MeV beam would only have a few millimeters of uniform energy deposition.

Protons must be several hundred MeV to deposit their energy uniformly and would require the construction of an extremely expensive machine. Since there [illegible] proton accelerators in existence, the[illegible] considered in evaluating facilities but not from the point of view of a new facility.

Study plan

This study was divided into two parts. The first part was to study existing facilities to determine how well they might serve the above described heating requirements. The second part was to estimate the feasibility of building a new beam heating facility.

Existing facilities

All the major "S" band linacs in the Country fall within about a factor of 2 of each other. They are capable of heating rates of about 100 calories per gram per second over a very small area. (About 1/4th of a square centimeter.) Over 10 square centimeters they can only produce heating rates of a few calories per gram per second. Table I shows the average rate of deposition of energy if the beam was one centimeter in diameter. In all cases the beam could be spread over a larger area with the resulting diminution in the rate of energy deposition.

The first two facilities, ORELA and LAMPF, are not set up for general users but may be used on a "not to interfere" basis. Also, in the case of LAMPF, the user cannot have the beam switched on and off at his discretion.

The three electron accelerators, NRL, White Sands, and Boeing, are set up for general users. They each cost in the neighborhood of $300.00 per hour, with a minimum time of eight hours.

No costs have been set up for the Brookhaven facility although they plan to serve customer needs. At present they must operate under a limit of 10,000 pulses per year for radiation safety reasons. (The neutron production by a 200 MeV proton beam is not trivial.) With so few pulses divided among all potential users indicates that there probably would not be enough pulses to make a beam heating experiment worthwhile.

A 250 kilowatt average beam power LINAC

A meeting was set up with representative accelerator building experts from Los Alamos to determine the feasibility of such a machine. Present were; Stan Schriber - overall accelerator design, Bill Stein - rf sources, John Fraser, injector design, and Ken Murray. The following questions were addressed:

Can such a machine be built with current technology?

If so, how much would it cost?

How much space would be required?

How long would it take?

What would be "off the shelf" parts?

What would be developmental?

The next section is an account of the consensus of that meeting.

Consensus

Although the average power of 250 kilowatts is needed for only one second out of a measurement interval which would probably be several minutes in duration, this fact was not felt to offer any savings in design. It was felt that, in order to achieve stability, the rf power would have to be on all the time. The availability of a 500 kilowatt CW klystron operating at "S" band (3giga Hertz) reinforced this viewpoint.

The following design parameters for a CW "S" band LINAC were stated:

First, an energy gain of 3 1/3 MeV per meter which would require 3 meters of accelerating wave guide to achieve 10 MeV. (A detailed design study might reduce this figure a little.)

Second, about 500 kilowatts of rf power would be consumed in the wave guide, hence one would have to use two 500 kilowatt klystrons to have power available for accelerating the electron beam.

Third, the injection system for this machine could consist of a Litton triode gun delivering up to one Ampere at 20 KeV plus sufficient rf preacceleration to bring the beam energy up to about one MeV. This system would occupy about two meters, bringing the overall length of the accelerator to about 5 meters.

Finally, a CW LINAC such as this would operate at an overall efficiency of about 10% (beam power /"wall plug" power times 100) requiring cooling tower capable of dumping about 2 1/2 megawatts.

A CW LINAC has one very significant advantage over other types of accelerators in that it is very quiet. i.e. with no large pulse modulators there are no transient signals injected on the line or ground returns, and there are no radiated electromagnetic transients either.

A very preliminary cost estimate

Accelerating wave guide plus associated plumbing.	$ 300,000.00
The rf driving system including the klystrons.	1,500,000.00
Injection system	100,000.00
Cooling tower (2 1/2 megawatt)	400,000.00
Total	$2,300,000.00

A detailed design study would cost about 10% of the final cost of the machine and would require about 1/2 a year to complete. It was estimated that entire accelerator could be completed in from 1 and 1/2 to 2 years.

Such an accelerator as this would make use of the following components and/or systems which are currently available or are simply a matter of duplicating existing systems:

1) Injection system.
2) 500 kilowatt CW klystrons.
3) Accelerating wave guide structures.
4) Cooling and vacuum systems.

Considerable work has been done at several labs on control and non-intersepting diagnostics however not at this power level. Some developmental work would be required to provide phase and amplitude control of the rf power and beam diagnostics for a 250 kilowatt electron beam. A more demanding developmental effort would be required for the exit window and beam dump as nothing has been done at such a high average power level for an electron beam in this energy range.

An alternative pulsed system

It is quite possible that a pulsed accelerator operating at something like a 1% duty cycle might be cheaper and should be investigated. Unfortunately, no one could provide any estimate of a suitable modulating system and power supply. It was felt that the cost of such a system might offset the savings resulting from a reduced cooling system, a shorter machine, and a somewhat cheaper rf driving system. The pulsed rf system was estimated to cost between $800,000.00 and $1,000,000.00 which would reduce the above estimate by $500,000.00. The accelerating gradient would be more like 10 MeV per meter which would require only 1 meter of accelerating wave guide and reduce the overall length to about 3 meters. For these reasons, the above preliminary cost estimate would represent an upper bound.

Space at the Naval Research Lab.

Building 75 at the Naval Research Laboratory was constructed to house nuclear research particle accelerators and presently houses a 65 MeV LINAC. There is shielded space for a machine such as the one discussed above in either of 2 locations in building 75. Rooms 123 and 125 could be combined by removing the separating wall and would provide adequate although somewhat cramped space for the machine. A larger and more flexible space is in room 103 parallel to the existing LINAC. Both locations are well shielded. Figure one is a floor plan of the 1st floor of bld 75 showing the existing LINAC and the possible locations of the beam heating machine.

Summary

This report can be summarized as saying that there is no existing facility that comes within a factor of ten of the needs of a high heating rate thermodynamic properties research facility. Also, that a facility could be built at the Naval Research Lab. for a cost in the neighborhood of 2 million dollars. The 10 MeV electron beam would not produce any serious radioactivity but would provide unprecedented beam power for such other applications as food processing, sewer treatment, materials curing, radiation hardness assurance, etc.

NRL LINAC Beam Characterization

Kenneth M. Murray

KM Sciences

Introduction:

The electron beam from the Naval Research Laboratory (NRL) linear electron accelerator (LINAC) is used as a source of ionizing radiation for the testing of devices and systems in the presence of such radiation. The energy, spatial, and temperal characteristics must be known accurately to ensure that such tests are meaningful.

Most device and system tests are carried out in room 105B of bldg. 75 at NRL. The electron beam comes directly from the LINAC into that room without energy discrimination. The normal procedure is to tune the accelerator on an energy analyzed beam line so as to achieve the desired beam energy. The deflection system is then turned off and the beam is allowed to go directly into room 105B. In general the exact energy of the electron beam is not critical because the rate of energy deposition changes only slightly over a wide range of energy. The most important parameters are the spatial distribution of current density and the shape of the electron beam pulse in time.

Method:

Figure 1 is a diagram of the beam line into room 105B. It shows a current transformer, an exit window, a berillium oxide chip used to render the beam visible, and a Faraday Cup consisting of three lead bricks. The six inches of lead is required to attenuate the bremsstrahlung produced by the beam stopping in the lead sufficiently that relatively few secondary electrons are produced at the back of the cup. The current transformer is compared with one at the exit end of the accelerator to ensure proper steering of the beam. The TV camera viewed the berillium oxide chip allowing the operators to center and focus the beam. This TV image gives some indication of the size and distribution of the beam, however the light output tends to saturate giving a larger than true impression of the size of the beam. For a pulse length of 1.5 microseconds, the maximum length attainable from the NRL LINAC, the maximum stable beam current is about 320 milliAmperes. For this current and pulse length one gets about 80 kilorads (Si) in a single pulse. The dosimeters used at NRL are calcium fluoride manganese activated thermoluminescent dosimeters (TLD). The light output of these dosimeters at such a dose far exceeds the range of linearity of the TLD reader. Hence, it was necessary to reduce the beam current until the dose in a single pulse was not more than about [illegible] kilorads. This was achieved at a current of 20 milliamperes. A beam profile was made at this current using a 5X5 array of adjacent TLD chips forming a continuous surface of TLD's about 5/8th inch on a side. Figure 2 shows a horizontal and vertical histogram made from that array. The TLD chips are 1/8X1/8 inch giving an area of 0.101 square centimeters. The dose read on a single TLD times the area of the TLD is proportional to the total number of electrons that have passed through the TLD. By integrating over the entire beam, one can determine the total number of electrons in the beam pulse. This quantity can also be determined from the current pulse read either on the Faraday Cup or the current transformer. (The current transformer and the Faraday Cup were compared and found to agree exactly within the accuracy of an oscilloscope measurement.) The following equation is the relation between the dose in rads (Si) and the number of 30 MeV electrons per square centimeter;

$$D = 2.9 \times 10^{-8} \times A \times N.$$

A is the area of a TLD. The sum of electrons passing through the TLD's as determined from this equation was 1.82×10^{11} while the total number of electrons as measured on the Faraday Cup was 1.85×10^{11}. This agreement was well within the experimental error. One can see from the histogram in figure 2 that the beam was about two chips (1/4 inch) in vertical extent, and about four chips (1/2 inch) in horizontal extent. This is in qualitative agreement with the TV image of the berillium chip. Here the peak current density appears to be about 120% of that determined by dividing the current reading from the Faraday Cup by the beam area of 0.8 square centimeters.

The 50 nanosecond pulse indicates a somewhat different picture. Figure 3 shows the horizontal and vertical histograms for that pulse. The beam is more tightly focussed with most of the beam in one TLD. The peak current density shown by the TLD's was 2.15 Amperes per square centimeter. This is not too different from the value of 2 amperes per square centimeter estimated by dividing the Faraday Cup reading of 0.8 Amperes by a beam area of 0.4 square centimeters. However since the dimensions of individual devices in an integrated circuit are on the order of a few hundred microns, the actual current density seen by such a small device could be quite different from the above figures because the beam could be focussed more sharply than is observable by TLD chips 1/8 inch on a side. For this reason it is advisable not to try and focus the beam to the finest possible spot unless on has available a dosimetry system with much finer spatial resolution.

Conclusion:

One can always achieve lower current densities by scattering the beam and moving the device under test further away from the scatterer. In this case one must rely on the TLD readings to indicate the dose rate at the point of interest.

For general utility with the beam covering about four TLD's fairly evenly one can claim that the NRL LINAC can produce a maximum dose rate of about 6×10^{10} rads (Si) per second for a pulse length of 1.5 microseconds, and about 1.4×10^{11} rads (Si) per second in a 50 nanosecond pulse. In both cases the beam area is about 0.4 square centimeters.

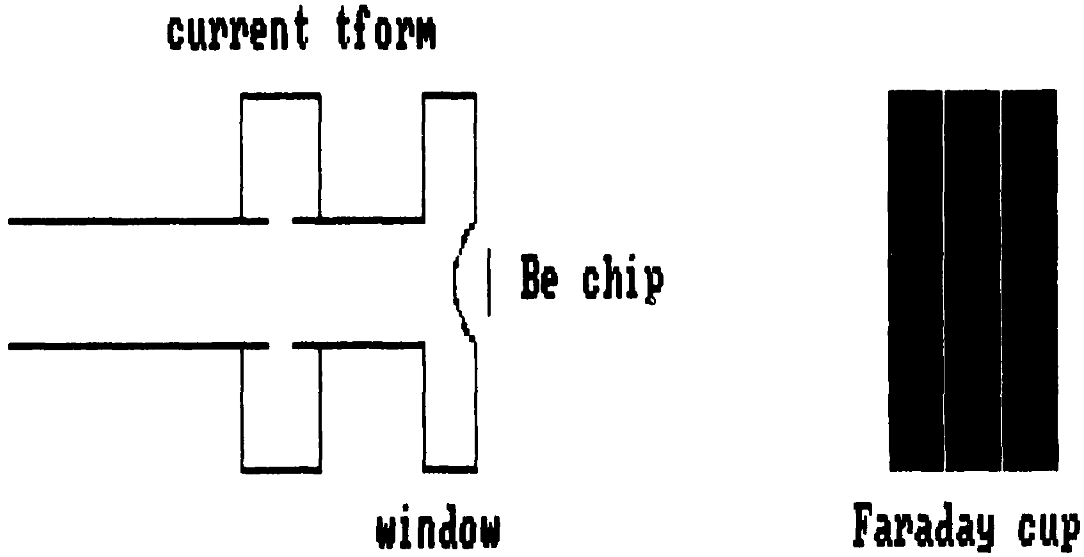


Figure 1. set up for beam characterization

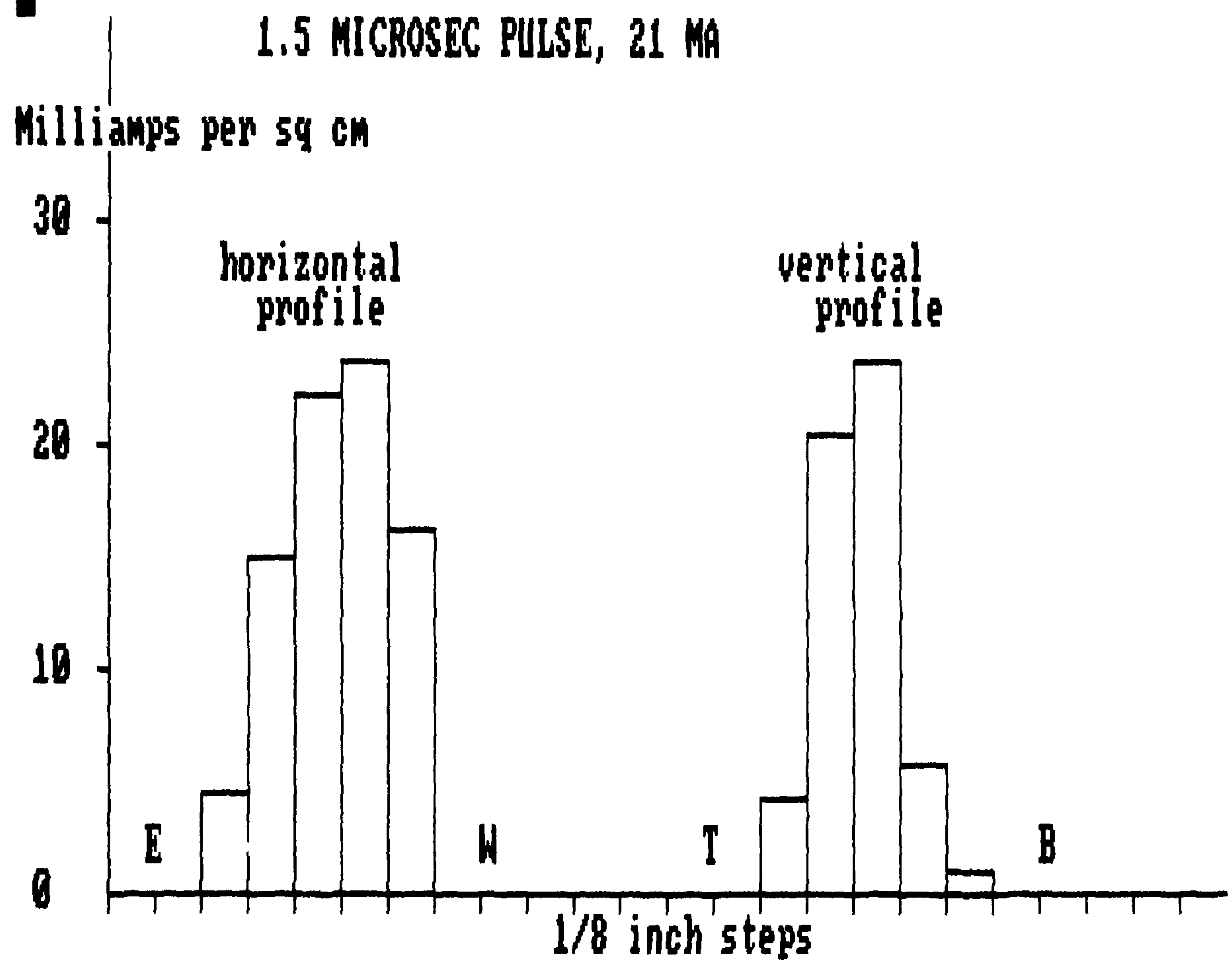


Figure 2 Beam profiles for a 1.5 microsec pulse

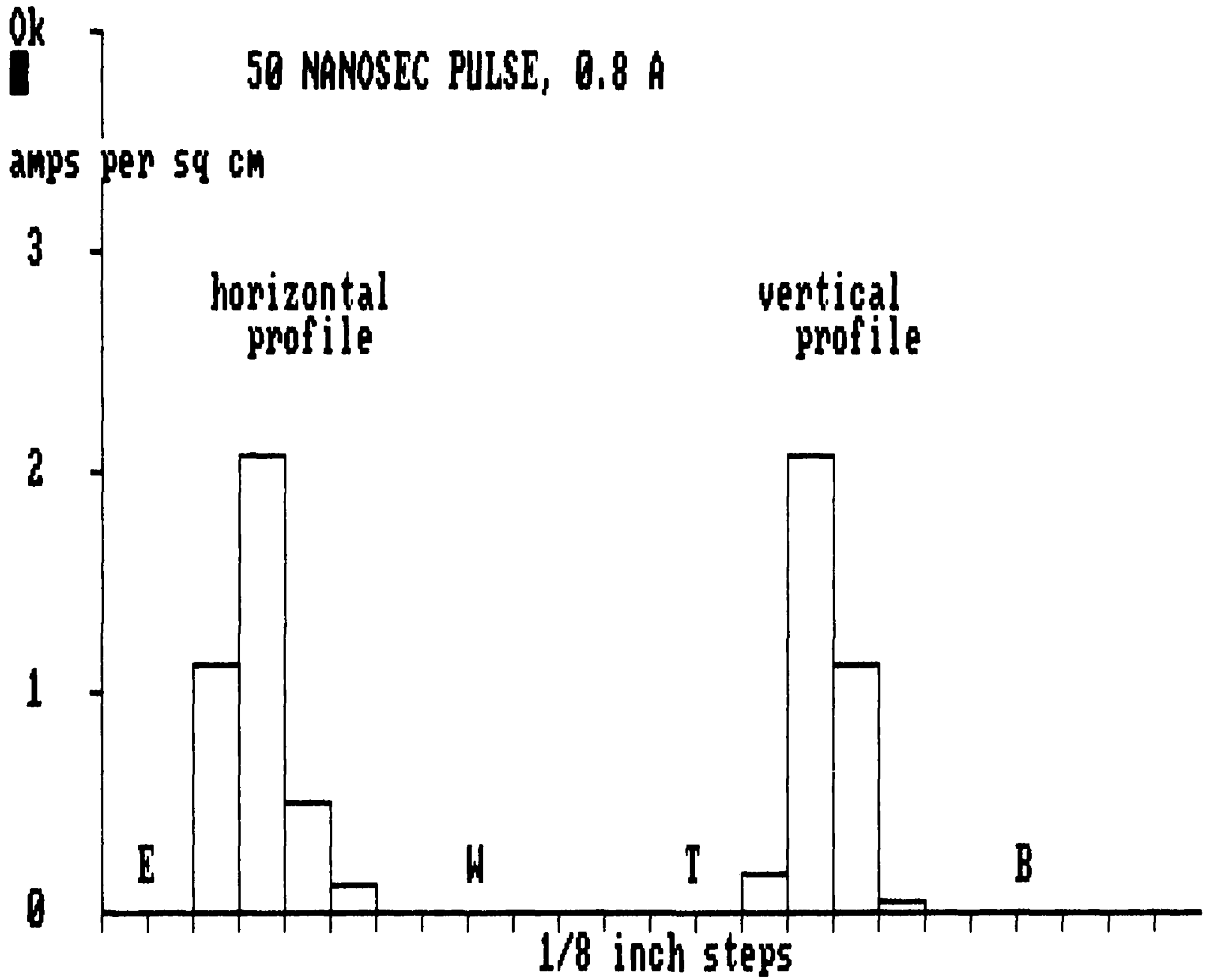


Figure 3 Beam profiles for a 50 nanosec pulse

RADIATION TESTS OF THE BALLAEROSPACE
RADIATION HARD BREADBOARD STAR TRACKER

KM SCIENCES
August 5 through 14, 1985

Introduction

This report is a chronology of the testing of the Ball Aerospace startracker at the Naval Research Laboratory (NRL) linear electron accelerator (LINAC) facility.

8-5-85

On monday, August 5th, three people from Ball Aerospace, Mike Hubbard, Debbie Murata, and Craig Schons, arrived at NRL with the breadboard startracker and associated test equipment. They indicated that they wished to perform low dose rate using the Co 60 source first.

While Ball was setting up their equipment and checking it out, KM Sciences used Thermoluminescent Dosimeters (TLD's) to check the field of the Co 60 source for inverse square law and reader calibration. Using the intensity figure of 36.4 Rads(Si) per minute at the face plate, The calibration of the LINAC TLD reader agreed to within 10%. The intensity figure was furnished be Dr. Leon August for the 6th of Aug., 1985. The rate at 2 meters from the source was 2 rads(Si) per minute. This figure was consistent with the inverse square law. (The face plate is 24 centimeters from the source.)

By afternoon Ball was ready to move the tracker and test equipment into the Co 60 test area. The tracker was set up at the 2 meter position with with an artificial star tube in place. Lead bricks were stacked to shield the electronics and allow only the CID detector array to be exposed to the gamma ray beam. The tracker was put through its normal modes of operation and gave no evidence that it was being affected by the gamma beam.

8-6-85

The observations of the tracker operation were repeated at the 2 meter position with the same results. The tracker was moved as close to the source as could be achieved and still have the artificial star tube in place. Again shielding was placed to limit the exposure to the detector array. TLD readings confirmed the calculated field at this point to be 20 rads(Si) per minute. The tracker was again operated and gave no indication that it was being affected by the gamma ray beam.

It was then decided that the tracker should be moved on to the dose rate tests in the LINAC beam. The tracker was moved to room 105B and checked out for proper operation at the irradiation area.

8-7-85

The LINAC was tuned to 40 MeV, with a 50 nanosecond pulse and a current of about 100 milliAmperes. The current could not be reduced below this value due to restrictions on the operating bias voltage at the gun. With the LINAC operating with these parameters, it was found that a scatterer consisting of 3/8 inch berryllium, plus 1 and 1/2 inches of aluminum were required to achieve a dose rate of 2.8×10^{6} rads(Si) per second at 61 inches from the scatterer.(This was the maximum distance from the scatterer at which the tracker could be placed.) A map of the radiation field at this distance showed a fall off to 1/2 of the central value at the edges of the tracker. (See figure 1)

the tracker was shielded with lead bricks such that only the detector was exposed and a series of single pulse shots were run with no sign of an effect. The shielding was then changed to shield the detector only and to irradiate the electronics. Again a series or single pulse shots were run with no apparent affect on the operation the tracker.

<u>8-8-85</u>

The LINAC was tuned the same way as on the 7th with a slightly higher current giving a central dose rate of 3.5×10^{6} rads(Si) per second. It was felt that the tracker might have different modes of sensitivity at different times in its operating cycle and that single pulse operation could miss a critical time. To try to catch these, trains of 100 pulses at a repetition rate of 180 pulses per second were used. These did cause upsets, however the tracker always recaptured the star. Trains of 10 pulses were tried and these did not always upset the tracker. The results were the same whether the detector or the electronics were exposed.

Next the beam current was increased to nearly one Ampere and the central dose rate was measured to be 1.8×10^{7} rads(Si) per second. Again the detector and the entire box were tested independently using singles, 10's, and 100 pulse trains with essentially the same results.

To get to a higher dose rate the tracker was moved to about 19 inches from the scatterer. here a central dose rate of 1×10^{8} rads(Si) per second was measured with a fall off of about 1/3 that value at the edges of the tracker. See figure 2. The detector and the box were irradiated independently with singles, 10's and 100 pulse trains. The upset rate was somewhat greater with the circuit boards indicating a somewhat greater sensitivity. The total dose was always monitored with TLDs.

<u>8-9-85</u>

In order to get to a dose rate of 10^{9}rads(Si) per second, the scatterer was reduced to 3/8th inch of berrylium and 1/4 inch of aluminum. The LINAC was tuned to 1 Ampere and this resulted in 1×10^{9}rads(Si) per second at the center of the tracker and fell off to 1/3rd that level at the edges of the tracker. The detector and the box were tested independently and the box latched up once, requiring a power down and restart to recover. This returned it to normal operation.

The detector was to be tested to 10^{11} rads(Si) per second. To achieve this the tracker was repositioned to place the detector in the center of the beam. TLD readings showed a dose rate of 4×10^{10}rads(Si) per second. Single shots were run as well as one 10 pulse train. Upset was observed with immediate recovery. The detector was then moved to about one inch away from the exit window. TLD readings indicated between 1.4×10^{11}

and 7×10^{11} rads(Si) per second on the detector. One single pulse was observed producing upset with subsequent recovery. No more pulses were checked because the detector total dose was now nearing 10 kilorads while the box had an integrated dose of about 5 kilorads.

It was then decided that the total dose tests be set up. The LINAC was tuned for a 1.5 microsecond pulse at a current of 260 milliAmperes. Scattering consisted of 3/8th inch of berrylium plus 1/4 inch of aluminum. The tracker was irradiated from the back as shown in figure 3. The box was 19 inches from the scatterer. Figure 3 also shows a map of the dose. The maximum dose rate was 1.5×10^{8} rads(Si) per second falling off to 1/2 that value at the edges, and about 1/10th that at the detector. This was due to the thick aluminum heat sink that the detector was mounted on. Using an average figure of 150 rads(Si) per pulse, 67 pulses were required to reach 10 kilorads. The system was irradiated with 67 pulse trains(10 kilorad steps), checking operation after each step. This gave a total dose of 100 kilorads average over the tracker. The system appeared to be functioning normally.

8-12-85

Monday,Aug., 12th, was devoted entirely to a detailed tare-down and check of the tracker and all its parts.

8-13-85

Ball had a program to read each pixel and record the data. They wished to redo the Co 60 observation with the detector as close as possible to the face plate. The closest that the detector could be placed to the face plate gave a dose rate of 27 rads(Si) per minute. Several runs were made in which the pixels were read and the source was turned on and off. These data were stored on diskette and will be analyzed later.

The tracker was then moved back to the LINAC beam. The plan was to irradiate the tracker end on at 19 inches from the scatterer, reversing its orientation every 50 kilorads to even out the dose distribution. However, TLD readings indicated too much nonuniformity due to the thick pieces of aluminum within the ends of the box. It was therefore decided that the best uniformity could be achieved by placing the tracker transverse to the beam at a distance of 61 inches. TLD mapping is shown in figure 4. There is less than a factor of two from lowest to highest reading. An average dose of 34 rads per pulse then required 1500 pulses to reach 50 kilorads. After the first 50 kilorad shot the system appeared to recover and reacquire its star. The second 50 kilorad shot resulted in a loss of ability to acquire any star. At this point the total accumulated dose was 200 kilorads.

The tracker was carefully checked to determine what had failed. This study indicated that some level shifters used to provide certain control signals to the detector were at fault. replacing them returned the tracker to normal operation.

8-14-85

The tracker was set up for further total dose runs. The dose rate was the same as the previous day. On the third 50 kilorad shot the tracker again lost its ability to acquire any star. Checking the level shifters indicated a similar mode of failure. Since there were no more replacement parts on hand, the testing was stopped and the people from Ball Aerospace packed their equipment and returned home.

	7.9	8.7	12
star tube	7.9	14	8.6
	8.6	11	7.3

FIGURE 1. Dose map at 61 inches, 100 pulses

	801	1607	1383	1148	771
star	1327	1864	2183	1519	1028
tube		1814	1652	1999	
	946		1432		890

FIGURE 2. Dose map at 19 inches, 305 pulses

101	140	84
188	217	121
94	158	108

Back end of box upstream

Figure 3. Dose map at 19 inches, 1 pulse

```
                    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
                    !                                    !
                    !  2820        3831        3384      !
          xxxxxxxxxx!                                    !
                    !                                    !
                    !  2844        4348        3995      !  Upstream side
                    !                                    !
          xxxxxxxxxx!                                    !
                    !  2914        3455                  !
                    !                                    !
                    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx


                    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
                    !                                    !
                    !                                    !
                    !                                    !xxxxxxxxxxx
                    !                                    !
                    !    3337          4324         2491 !    3035   Downstream
                    !                                    !
                    !                                    !xxxxxxxxxxx
                    !                                    !
                    !                                    !
                    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
```

FIGURE 4. Dose map at 61 inches, 100 pulses

END

FILMED

12-85

DTIC